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CARNATION ROOT-KNOT.

H. GARMAN.

LEXINGTON, KENTUCKY.
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Kentucky Agricultural Experiment Station.

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Lexington, Ky.

*Deceased.
**On leave of absence.

BULLETIN No. 142.

CARNATION ROOT-KNOT.

By H. GARMAN, *Entomologist and Botanist.*

Mr. John A. Keller, Florist, of 131 West Main Street, Lexington, brought to the Station recently, three carnation plants, two of which were in a diseased condition due to an extensive development of swellings and knotty growths on the roots. The plants were decidedly dwarfed and presented other evidences of enfeeblement, plainly the result of the abnormal condition of the roots. It was a case of injury due to the attacks of the microscopic eel worm, long known in European countries, and more recently giving trouble in this country, at the North in hothouses, chiefly on roses, and at the far South on a great variety of herbaceous and woody plants when growing either in-doors or out. The carnation is not very commonly mentioned as a plant subject to attack, but cases have been observed by others, and knowing the wide range of plant food accepted by the worms, it would be more surprising than otherwise to find it exempt.

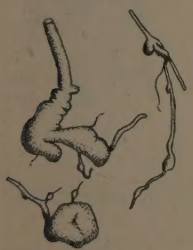

FIG. 1.—Eel worm nodules on the roots of carnations. Natural size.

Examination showed the roots very irregularly and extensively knotted from bases to tips, the masses varying from a sixteenth to half an inch in diameter, and from spherical and oval with smoothish surface, to irregularly lobed forms, the growths sometimes forming continuous lumpy swellings more or less continuous along the roots.

By slicing the nodules with a sharp knife and examining with a good hand magnifier, the pear-shaped swollen bodies of the female worms became clearly visible, and with a needle could be freed in numbers from the cavities they occupied in the plant tissue. A sec-

tion of a moderately large nodule sometimes showed a dozen or more of these swollen females lodged in the tissues.

The eel worm producing these knots is a true worm belonging to the same animal group as the common fish worms. It is not very closely related with the insects, and differs from the fish worms not only in being minute in size, but in having its body-wall continuous and not divided into segments. The worms composing the group to which it belongs are often known as thread-worms (Nematoda), because of the slenderness of the examples commonly encountered. The Trichina of pork is a member of the group and is not very different in shape from the immature eel worm of carnations. The Vinegar Eel also belongs to the group.

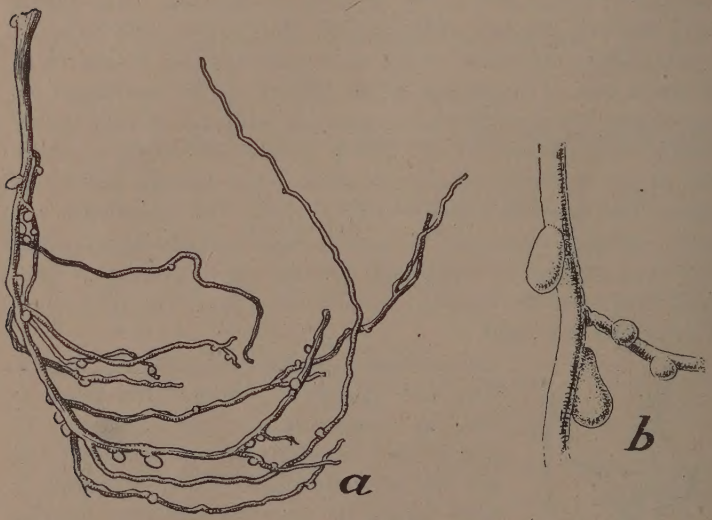

FIG. 2.—Bacterial nodules on the roots of red clover. *a*, natural size; *b*, enlarged.

The eel worm just out of the egg is snake- or eel-like in general shape, having no appendages of any sort, and lacking even the sense organs, such as feelers and eyes, commonly present in insects.

These slender worms push their way into the roots of sound

plants and settle down in small cavities. Both sexes are eel-like at first and are scarcely distinguishable, but the females soon increase greatly in size and from being microscopic grow to such size that they can easily be recognized by a good eye, the cross diameter being finally about 0.02 inch. When they reach this size they are incapable of locomotion, and except a slight movement of the head end of the body, present no more evidence of being alive than a small seed. The bodies are, in fact, little more than egg-sacs, and old individuals appear to die where they lie in the root, leaving the cavities they occupied filled with their eggs.

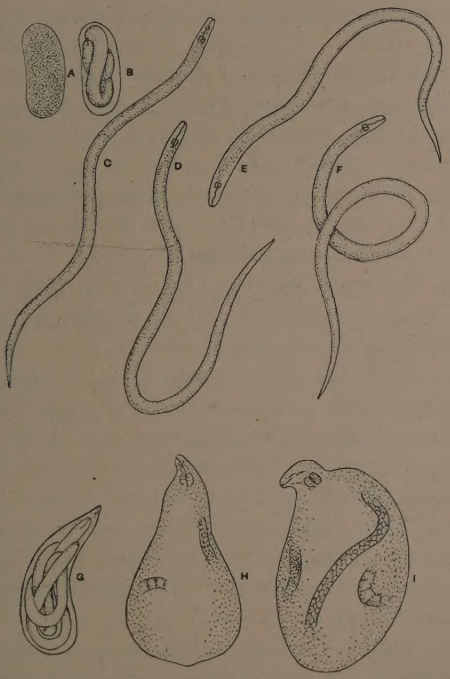

FIG. 3.—Showing the different forms of eel worms found in carnation root-knots. A, B, eggs; C, D, E, F, young eel worms; G, the male eel worm as seen in thin slices of root-knots; H, I, distended female worms as they appear in slices of carnation root-knots. All highly magnified.

When the young worm hatches it bores out of the cavity and through the root until it reaches the soil outside, and is then ready to invade other plants. When in this active condition worms are more easily killed by applications of oils or bisulfid of carbon than at any other time, but in dealing with them, it must be remembered that the eggs and adults in the roots must also be killed, else the soil may soon become reinfested.

PROBABLY AN INTRODUCED PEST.

European sugar beet and turnip growers have been greatly troubled with an eel worm known in the literature of the subject as *Heterodera schachtii*. It has been thought to be identical with the species occurring in America. But Dr. Neal, who first studied our species carefully, considered our eel worm different and gave it the name *Anguillula arenaria*. Dr. N. A. Cobb, writing in 1897 in the Agricultural Gazette of New South Wales, expressed the opinion that the eel worm of our South Atlantic States was identical with one found by him in Australia, and employing Neal's species name, called it *Tylenchus arenarius*. Following Professor Atkinson's lead, the American worm has often been referred to under the name *Heterodera radicicola*. These differences of name employed are likely to be confusing to one not posted on the science of the subject, but if the practical man simply keeps in mind the facts that in the South we have a knot-producing eel worm that works on various plants out of doors and that at the North, the same or a very similar worm is sometimes troublesome in hothouses where it attacks plants in precisely the same manner, he need not concern himself about the identity of species. It appears to me, after following the writings of both American and foreign writers, that our eel worm is the same as that described from Germany under the name *Heterodera radicicola*.

Accounts of injuries from eel worms began to become frequent in European journals devoted to floriculture about 1890, probably, it is supposed, because of an increased interest in the study of plant diseases which had begun to develop, and not because the worms were more common than they had been. American florists began to complain of the injuries about 1896, the most serious

trouble being at that time experienced with roses. Since then root-knot has, from time to time, given trouble in many localities, though generally in northern latitudes to plants grown under glass.

PLANTS ATTACKED.

In hothouses the eel worm has been troublesome in Kentucky from its attacks on cucumber, lettuce, tomato, and tobacco, the two latter plants suffering severely at one time in a Station conservatory. When once numerous in a soil it must be remembered that most plants will become infested if placed there.

As showing the wide range of plants attacked, the following imperfect list is given:

Almond, aster, bean, beet, Begonia, blackberry, cabbage, Coleus, corn, cotton, cowpea, cyclamen, Dahlia, egg-plant, English walnut, fig, gourd, grape, Hibiscus, Japan clover, melon, morning-glory, okra, parsnip, pea, pear, peach, Petunia, plum, potato, radish, rose, spinach, sunflower, squash, tomato, violet.

TREATMENT

Soaking soil with coal oil emulsion, a two per cent. formalin solution, nicotine solutions, and the like, can be made to destroy the young worms when free in the soil. After they are imbedded in the roots of plants it is not worth while to try to kill them, unless one is willing to kill the plants at the same time, and when one is ready to do this, the best way is to take them up entire and burn them. The soil may then be soaked as long and with as strong preparations as is desired.

Lime water, nitrate of soda, and many other substances, have been recommended as effective in clearing soil of the worms, but it is not certain that any one of them can be depended on.

Fumigation with bisulfid of carbon kills the free worms, but cannot be used strong enough to destroy them without also destroying the plants. It can be bought of druggists in pound bottles, and may be introduced in soil by making a hole, pouring some of the fluid in it, and filling again with soil. While treating soil it is well to enclose it completely to prevent the too rapid escape of the fumes.

In 1893, W. N. Rudd, described in the American Florist a plan devised by him for disinfecting soil to be used in hothouses, his purpose being to kill grubs in the soil. He used a bin with the dimensions 20 by 6 by 4 1-2 feet, well braced, and with a run of three 1 1-4 inch steam pipes at the bottom, the pipes with 3-16 inch holes drilled eighteen inches apart along the sides. Soil intended for his benches was first placed in this bin and steamed until potatoes placed on the surface were cooked. Hotbed sashes were used as a cover.

Steam was found later at the Ohio and Massachusetts Stations to be a very effective agent for disinfecting soils, and has been used also here for the same purpose. It has the advantage over dry heat of leaving soil in good condition for immediate use. For a good many years we have made use of a roughly constructed brick oven, with a flue at one end and a cover of sheet iron, for disinfecting small lots of soil from infested pots, and find it completely effective for all sorts of pests. More recently for such sterilization we have used an ordinary gas range, placing the soil to be sterilized in the oven in bake-pans. Such conveniences can be made to check the spread of pests when recently introduced, but where steam is available it is to be preferred, and especially where it is desired to disinfect the soil of a whole bench.

Professors Stone and Smith of the Massachusetts Station found that it was possible to kill the worms in soil by heating it to a temperature of 140 degrees F. This is in contradiction to assertions made by some practical growers to the effect that it is necessary to employ a temperature of 212 degrees or more. It seems to be a question of thoroughness of application. A temperature of 170 degrees F. will certainly kill eel worms, and it only remains to apply steam to infested soil so that every portion reaches this or a higher temperature. The experimenters mentioned, found they could accomplish this result quickest by laying three parallel courses of tile in a bench, as if for subirrigation, connecting them at each end. The steam was then introduced at one end of the bench, being supplied by a 4 horse-power portable boiler with a capacity of 40 to 80 pounds pressure. When narrow benches are tiled in this manner the work can be done in from an hour and

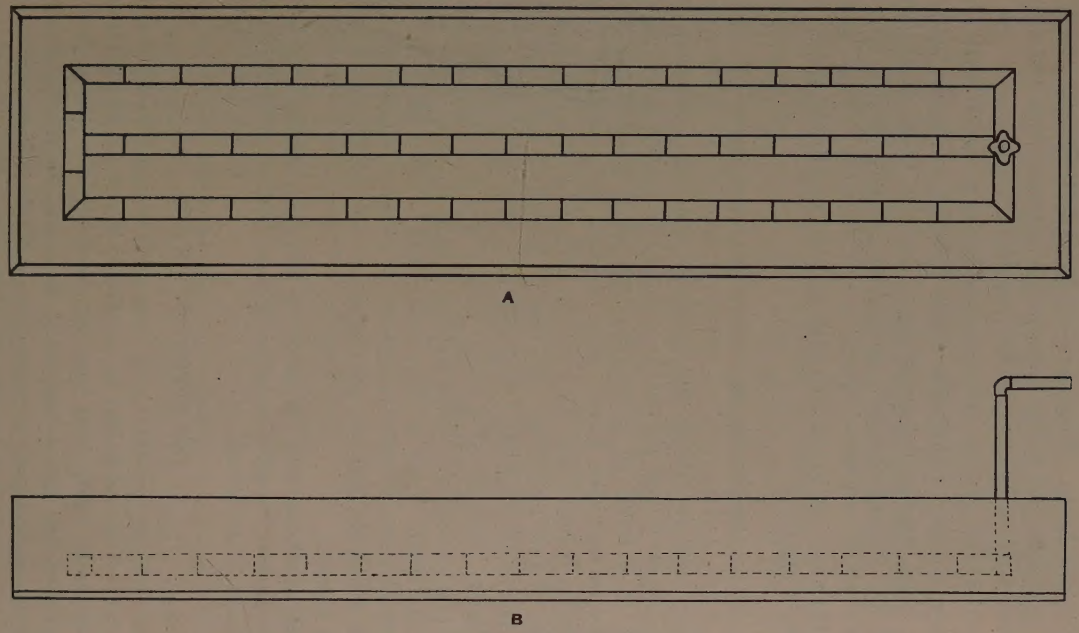

FIG. 4.—A, Surface view of a hothouse bench, showing best arrangement of tile for steaming soil; B, side and sectional view of same, showing the steam supply-pipe at one end. (After Stone and Smith.)

a half to two hours. Where only two courses of tile were used and these were left open at the ends opposite that at which steam was introduced, the time required was greater.

Practical rose growers have employed steam in similar ways with complete success. It has been found desirable to enclose the soil when being steamed as completely as possible, using in the case of benches a cover of boards or blankets. Some provision for the removal of the condensed steam is also desirable. When tile is used the water can be removed with sufficient rapidity by giving the courses a slant.

FREEZING DESTROYS EEL WORMS.

Fortunately for florists and gardeners residing in the northern states, the eel worms are unable to stand our winters out of doors. When as a result of transferring soil or infested plants from benches of hothouses during warm weather, soil outside becomes infested, it is found that the worms do not persist over the following winter. I have known one such case in Kentucky, and it has been the experience of others. Exposing soils to frost is thus a very satisfactory recourse for northern florists, and it is only necessary to empty benches of infested soil and spread it out of doors when the temperature is low in order to disinfect it completely. Worms are known, however, to have persisted out of doors in manure heaps, where it may be supposed the temperature in the center was kept above freezing.

This sensitiveness of the worm to cold will, however, probably always restrict its injuries in America to hothouses, north of the 35th parallel of latitude.

THE EFFECT OF DRYING.

The claim has been made that thoroughly drying soils will destroy the knot worms, but it may be questioned if soil can be disinfected by this means unless it is kept completely dry for a long period. Disinfection has been accomplished, it is said, by leaving the soil of benches in hothouses over summer completely exposed to the sun, and with the added precaution of stirring it up from time to time to ensure complete desiccation.

Some recent experience with thread worms tends to show that they will stand prolonged drying when in soils, and although rendered torpid by it, recover again when moisture is supplied.

SUMMARY OF REMEDIES.

1. If plants are already so badly infested that nothing is likely to be gained by preserving them, they should be taken up entire and burned.

2. If likely to produce some flowers, this may be delayed until they can be cut, then all parts of the plants should be burned.

3. In a severe winter, it is only necessary to remove the soil from infested benches, and put it where it will be thoroughly frozen.

4. If the summer season is at hand, it may be put in a shallow bin and dried thoroughly, but to make its disinfection sure, should be left out of doors during the following winter.

5. Bisulfid of carbon and formalin solutions can be made to destroy free worms in soil, but none of the substances tried (lime, kainite, coal-oil emulsion, carbolic acid, tobacco extracts, etc.) can be depended on to disinfect soils while still occupied with living infested plants. In other words, it is impracticable to kill eel worms in the roots of plants without at the same time killing the plants.

6. Dry heat and steam are satisfactory agents for disinfecting soil, and not only clear it of eel worms, but also of parasitic fungi causing drop and rot, as well as other pests.

7. Plants received with knotted roots should never be admitted to a hothouse since they are likely to lead to a more extensive infestation with eel worms.

8. For out-of-door treatment, the practice recommended by the European experimenter, Kuhn, of planting trap crops is about the only treatment found at all practicable. The young worms developed in roots are found to leave the plants at the end of five weeks. A crop of sugar beets, or some other plant to which the worms are partial, is sown and at the end of four weeks is taken up and destroyed, or fed to stock. Several crops treated in this fashion reduce the worms, so that subsequent sowings are but little injured.

LITERATURE.

Frequent references to eel worm injuries appear in the Gardener's Chronicle (London) from 1890, onward. In the American Florist, the pest began to receive notice in 1896, though some of the communications indicate that at least one writer did not recognize the difference between knots caused by eel worms and those produced on the roots of clover and other leguminous plants by bacteria.

The earliest American work giving special attention to remedies for their injuries, was published in 1889 as Bulletin No. 20, of the United States Division of Entomology. Its author, Dr. J. C. Neal, conducted his observations and experiments in Florida.

Prof. G. F. Atkinson, then of the Alabama Station, followed with additional observations on habits and life history, his work being published in 1889 as Bulletin No. 9, New Series.

Dr. N. A. Cobb published observations on the worm occurring in Australia in Miscellaneous Publication, No. 149, Department of Agriculture, New South Wales.

In 1898 appeared the results of a very satisfactory piece of work on the subject from the pens of Professors George E. Stone and Ralph E. Smith, of the Massachusetts Agricultural Experiment Station, being Bulletin No. 55 of the Station Series.

In Europe, Dr. M. Hollrung, J. Ritzema Bos, A. Zimmermann, and others have published articles on the eel worm occurring there.

Professor C. P. Lounsbury, Government Entomologist, writes, in 1904, of the injuries in South Africa, in the Agricultural Journal, applying the name *Heterodera radicicola,* and holding that the knot-producing eel worms of Europe, Australia and America are one species.

FIG. 5.—A, A healthy carnation plant; B, a plant injured by eel worms.

Fig. 6.—Showing the knotted roots of a carnation plant. Natural size.

FIG. 7.—Young lettuce injured by eel worms. Natural size.

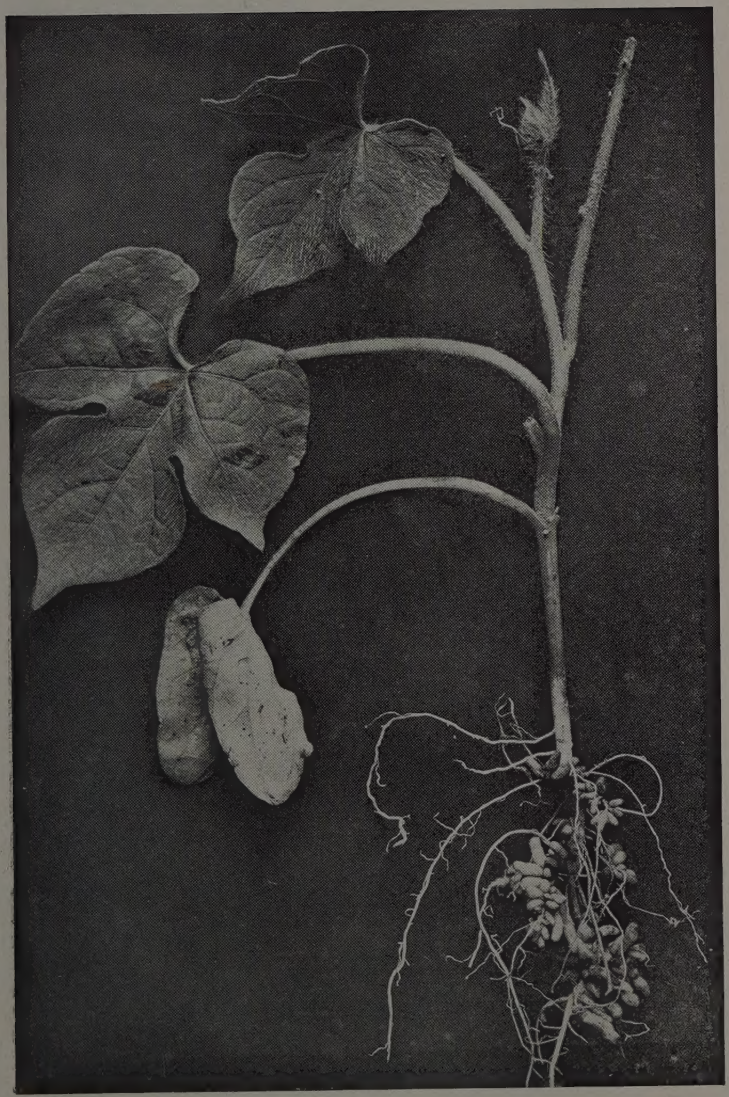

FIG. 8.—Ivy-leaved morning-glory plant (*Ipomoea hederacea*) with starch-containing tubercles on roots. Not due to either eel worms or bacteria. Natural size. Photographed in 1906.